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Methodology to Prioritize Climate Adaptation Measures in Urban Areas. Barcelona and Bristol Case Studies

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Received: 22 May 2020; Accepted: 8 June 2020; Published: 12 June 2020

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Abstract: In the current context of fast innovation in the field of urban resilience against extreme weather events, it is becoming more challenging for decision-makers to recognize the most beneficial adaptation measures for their cities. Detailed assessment of multiple measures is resource-consuming and requires specific expertise, which is not always available. To tackle these issues, in the context of the H2020 project RESCCUE (RESilience to cope with Climate Change in Urban arEas), a methodology to effectively prioritize adaptation measures against extreme rainfall-related hazards in urban areas has been developed. It follows a multi-phase structure to progressively narrow down the list of potential measures. It begins using less resource-intensive techniques, to finally focus on the in-depth analysis on a narrower selection of measures. It involves evaluation of risks, costs, and welfare impacts, with strong focus on stakeholders' participation through the entire process. The methodology is adaptable to different contexts and objectives and has been tested in two case studies across Europe, namely Barcelona and Bristol.

Keywords: climate change adaptation; climate risk; socio-economic assessment; urban resilience

1. Introduction

There is an increasing movement of local policy-makers to act against climate change, urging to adapt their cities and improve their resilience with suitable policies [1]. Designing and implementing general local-scale policies requires multidisciplinary studies and taking broad assumptions to address uncertainties, in order to maximize the welfare associated with a desirable outcome, such as improving public transport [2]. Climate change adaptation policy making has additional complexities. In the design phase, which is the scope of this paper, there are uncertainties related to climate predictions, vulnerability, and risk impacts, as well as socio-economic, technological, and environmental future trends that complicate the understanding of the potential outcome of a measure [3]. In addition, they have a cross-sectoral nature and diversity in terms of typology (e.g., structural, nature-based, or digital), scales (from a building to national scale), and timescales (short, medium, and long term) [3]. These complexities undermine measures' assessment results that consider only one criterion. Therefore, a systematic prioritization assessment is required in order to support the selection of the most suitable set of measures for each city under a changing climate context.

The purpose of the assessment of climate change adaptation measures is to minimize the degree of uncertainty when selecting policies that reduce the impacts of the changing climate [2]. For this purpose, technical and economic assessment approaches are usually considered (or a combination of them), as they provide relevant information about the costs and expected physical effects of the measures. However, in general, the degree of uncertainty of the results is linked to data availability and specific technical expertise to carry out detailed assessments. Therefore, when selecting a method, such limiting factors (i.e., data and skills availability) should be considered.

The present work has been developed in the context of the H2020 project RESCCUE [4], where a number of innovative models and tools were developed in order to help urban areas to become more resilient to climate change. One of the tools is the present methodology that aims to facilitate the ranking of all available adaptation measures considering the particularities of each city. Results are presented for Bristol and Barcelona (Figure 1), two of the three case study cities, to display the different approaches taken by each city.

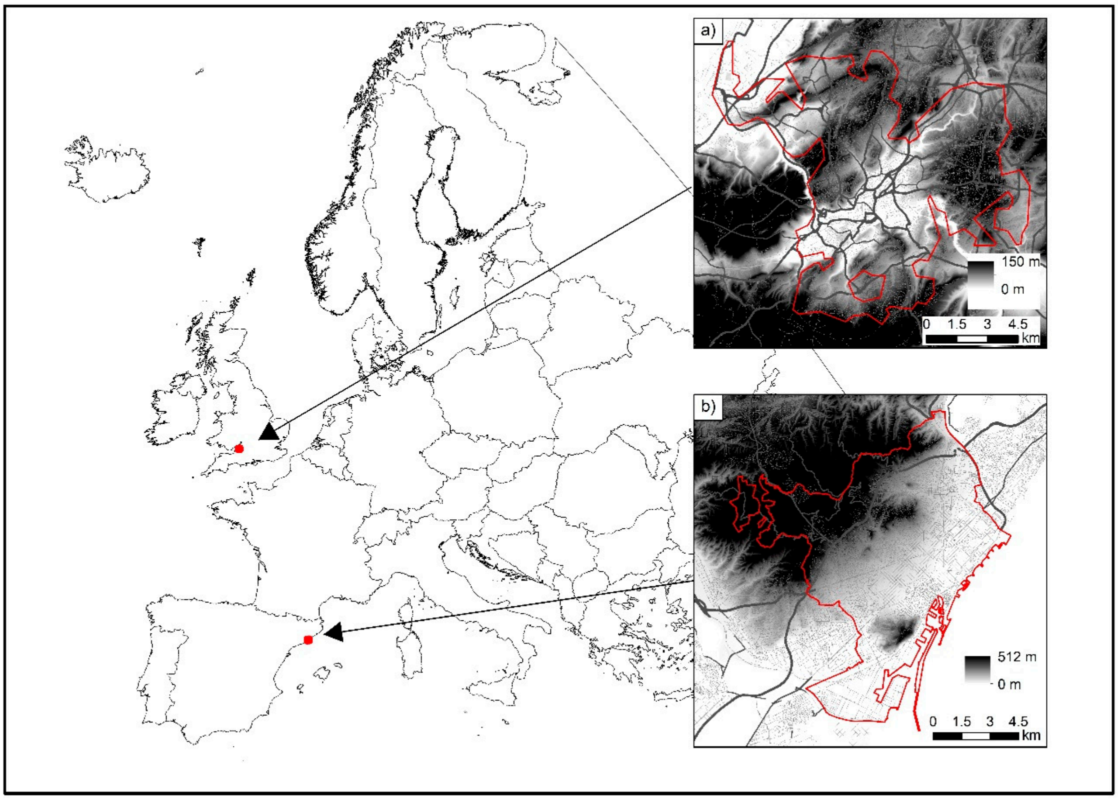


Figure 1. Location of the two cities where the methodology has been applied: (**a**) Bristol, United Kingdom and (**b**) Barcelona, Spain.

Section 2 summarizes the main methods used to evaluate adaptation measures. Section 3 starts with a brief description of the key terminology, and it is followed by the description of the methodological approach, presented by stages. Main methodological differences between Barcelona and Bristol studies are presented in order to compare the different approaches taken. The results for both case studies—Section 4—are also divided by stages. In the discussion, results are commented, as well as the main challenges found when applying the methodology and recommendations for further application of the methodology. The conclusion summarizes the main results.

2. Literature Review

A deep analysis of the most relevant methods in the field was carried out to understand the potential applicability to the context of the project RESCCUE [4]. A brief description of them is presented in order to provide context.

- Cost-effectiveness analysis (CEA) is a simple method that offers guidance to rank different alternatives, providing a ratio of necessary investment to achieve a unit of effectiveness (to be selected based on a pre-set objective) [5]. It is attractive as it can quickly scan and rank different options whose benefits are not easily measurable. Although it has limitations on assessing whether the policies are "worth doing", in the sense that it does not determine whether benefits are greater than costs [6] and lacks the capacity to identify non-direct impacts [7].
- Multi-criteria analysis (MCA) is a multi-step method based on the synthesis of already existing assessment studies [3]. It has diverse forms, but the general MCA method uses a scoring system to determine the potential accomplishment of a policy objective, giving weights (allocated by experts) to the different indicators included, previously normalized [8]. The major benefit is the possibility to assess variables of different nature and scales into the same framework (i.e., monetary, quantitative, or qualitative data). This is at the same time its major disadvantage, as trying to simplify and normalize different units and criteria can lead to a loss of accuracy [9]. Another characteristic of MCA is the consideration of multiple stakeholders in the evaluation process of indicators that are not measurable with quantitative data. If participants are impartial experts in relevant fields, results will be relevant, otherwise the scores risk being biased [6].
- Risks reduction assessment involves assessing either the health or environmental risks (or both) attached to a policy or project [6]. It is a valuable method for urban adaptation and mitigation appraisals as it is based in the concept of the disaster risk triangle (hazard, vulnerability, and exposure) [10]. It provides detailed results in terms of probability of damage for the selected return periods for the design storms, which facilitate the estimation of the potential damage reduction indicators compared to the do-nothing option [11]. A significant disadvantage of the method is its high time resources and specialized personnel requirements.
- Cost-benefit analysis (CBA) is a popular method to appraise the expected net results of different investment or policy options. It considers all costs and resulting benefits through the project or policy life, including economic (actual revenues and costs), social, and environmental changes derived from their implementation, through different available monetization methods [6]. In addition, in the context of natural hazards, this monetization usually implies consideration of risk reduction efficiency.

In order to address these challenges, the methodology was designed taking the most relevant parts of each method. It follows an MCA approach on its structure, to accomplish a gradual down-selection process. The initial "wish list" of measures is assessed and ranked in a first stage using the CEA method and co-benefits scoring, since they require less resources (time and expertise). After a first selection based on the initial results, most of the efforts are put in the last steps where only a small number of measures are studied in detail. The detailed assessment consists in exhaustive risk assessment and CBA.

3. Methodology

The proposed prioritization methodology was developed to offer a flexible approach, able to adapt to different urban contexts. The balance between expertise, resources requirements, accuracy, and replicability of results was an important consideration during the design process. The capacity of the methodology to allow for different levels of detail was also considered, due to the diverse data availability, which normally limits the assessment potential. Meeting these requirements was made possible by developing a method that followed the principles of MCA, in the sense that it (i) gives relevance to stakeholder decisions; (ii) uses normalized quantitative and qualitative indicators through a scoring system; (iii) is able to rank options with different goals [9]; and (iv) offers a multi-phase analysis approach. The phases are composed by combinations of assessment methods, ordered from coarser to more detailed assessments. The first stage includes a CEA and co-benefits scoring assessment, whereas the following phase is based on more detailed assessments—risks reduction assessment and CBA. In addition, the methodology proposes several variables to rank results that help decision-makers to downselect the most suitable measures for their specific policy goals. An introductory diagram of the methodology is available in Figure 2, which will be further explained in this section. In addition, the key terminology employed in the present methodology and the stages proposed to apply it is presented.

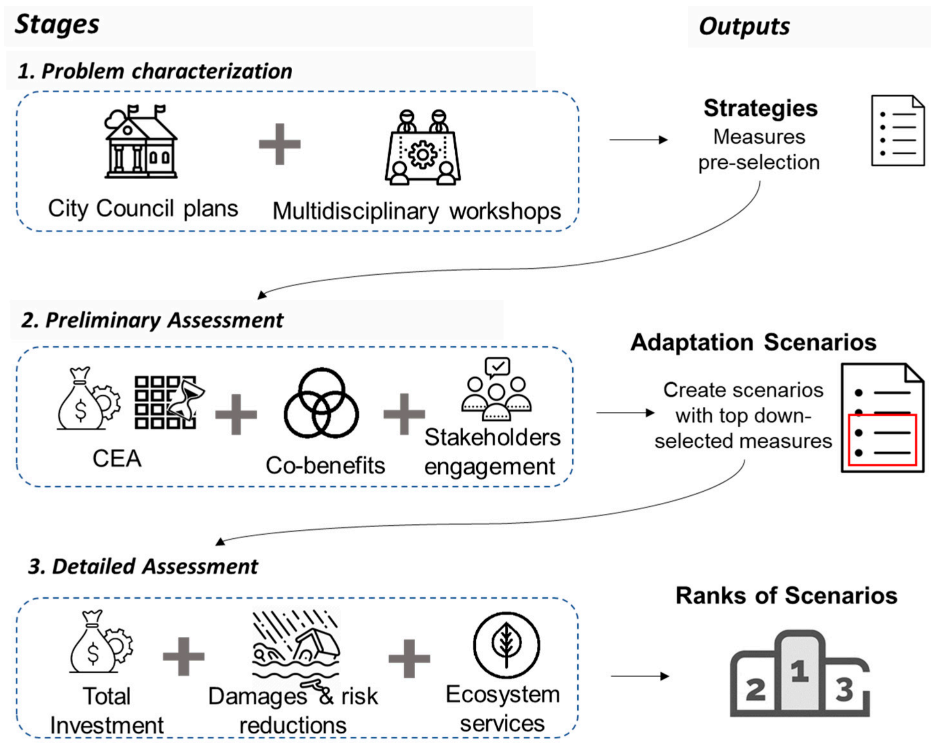


Figure 2. Outline of the methodology stages and outputs.

3.1. Key Terminology

The main terminology comprised in the proposed prioritization method could be summarized as follows:

1. Adaptation strategies are understood as sets of measures that aim to tackle one concrete issue related to climate change adaptation. Measures contain specific actions targeted to address a problem within the scope of the strategy they belong to. It means that a measure can be displayed in more than one strategy, because it tackles more than one problem (e.g., green areas could support flooding control and air pollution strategies).
2. Initial and recurrent investments of each measure are required. As it is an ad-hoc analysis, costs are expected to be estimates transferred from similar actions in different locations, scaled to the new location's size. It can be done using unitary values (€/m^2), and GDP to adjust through the purchasing power parity index [12] and exchange rate if necessary. For accuracy purposes, researchers should always try to find budget references from sites as similar to the research site as possible.
3. Economic, social, and environmental co-benefits are those benefits or positive effects generated in parallel to the main objective of the policy [13], understood as the specific climate change adaptation goal. Specific indicators for each co-benefit category, are presented in Table 1 below.

The quantification and monetization of co-benefits is surrounded by uncertainty [14], thus co-benefits were accounted for using a specific scoring system evaluated by experts from diverse disciplines in each case study. This method also involves uncertainty, but the method is less time-consuming and considers local knowledge.

4. An effectiveness indicator helps to assess the success of the resources used in achieving the objective of each measure [15]. It is important to select one that is valid across measures of different characteristics, and that requires available information. The effectiveness indicator selected in the present study is the reduction of downtime of urban services after an extreme weather event—recovery time reduction. This indicator provides information about the duration of modeled floods scenarios, and if scenarios with and without measures are compared, the variation of recovery time can be used as an effectiveness indicator.
5. Climate risks reduction is understood as a percentage of high-risk area reduced, may be used as an indicator of the adaptation effectiveness. The higher the number of risks assessed, the more comprehensive the prioritization of adaptation measures would be. Risks, such as the stability of pedestrians or vehicles exposed to water flows and damages caused to properties and vehicles, have been assessed among the case studies presented herein. Results are sought for both the business as usual scenario and the scenarios where adaptation measures are implemented.

Table 1. Representation of the categories of co-benefits and their indicators scored from 0 to 10 with expert judgement.

Economic	Social	Environmental
Cost savings	Reduced mortality impacts	Improved air quality
Reduced energy losses	Reduced health impacts	Improved water quantity
Job creation	Reduced mortality from diseases	Reduced aquifer depletion
Possible reduction in prices	Enhanced public amenity	Reduced water pollution
Increased labor productivity	Reduced impacts on vulnerable groups	Reduced land contamination
Increased economic production	Reduced number of householder/business forced from home/workplace	Improved biodiversity and ecosystems
Increased property values	Social inclusion	Maintained and increased green space
		Reduced environmental impacts through associated awareness
		Increased biodiversity and ecosystem services
		Effective/uninterrupted water collection and security
		Erosion control
Average (economic) = ∑ Scores/number of indicators (n = 7)	Average (social) = ∑ Scores/number of indicators (n = 7)	Average (environmental) = ∑ Scores/number of indicators (n = 11)

3.2. Stage 1: Problem Characterization

The first step was to identify the most pressing bio-physical and socio-economic issues [16]. Climate change scenarios and their impacts on the cities under study were required. In most large European cities, climate change predictions are available [17] and climate plans that address their major concerns with regards to climate change adaptation and/or mitigation [1].

In the current case studies, the downscaled climate-model projections used were developed by the FIC (Climate Research Foundation) [18], while Bristol used also climate data derived from UK Climate Change Projections 2009 (UKCP09) [19]. Local climate action plans were considered, as well as the conclusions from local workshops conducted to address the most pressing issues identified by stakeholder engagement in each site. A common workshop structure was proposed and followed by each city, adapting details according to their specific needs, such as the number and background of members. The main structure followed in the first workshop included context introduction, a discussion among partners regarding the approaches taken, strategies to be included, and the prioritization method to follow. The second workshop focused on reviewing the expected outcomes in terms of hazard reduction and the presentation and discussion of detailed strategies already identified by the city council.

The outcome, presented in the results section, was a selection of the extreme events and hazards to address and the development of a longlist of measures that are expected to alleviate the impacts of the former).

The second step consisted in selecting and applying a categorizing criterion to create strategies that are aligned with the objectives sought. In the context of urban services, the following options were proposed:

- By type of hazard (e.g., flooding events and droughts);
- By specific urban service targeted (e.g., transport, energy, and water supply);
- By type of measure (e.g., engineering, nature-based, or technological).

Researchers of the Barcelona case study decided to categorize strategies by the type of hazard they targeted, namely pluvial flooding and Combined Sewer Overflow (CSO), according to the objective of the city's stakeholders to focus on the reduction of those impacts. Similarly, the Bristol case study chose to categorize strategies by the predominant hazards identified in the city, which were pluvial and fluvial flooding and CSO events. These issues were forecasted to cause significant disruption to many aspects of the communities, in particular to the transport network, power supply, and properties located in high-risk areas.

This classification permits comparison of measures that "compete" against each other to alleviate one specific hazard instead of an overall prioritization of measures earmarked for different issues.

3.3. Stage 2: Preliminary Rank of Adaptation Measures

The preliminary assessment phase served as an overall screening of the extensive list of adaptation measures considering cost, effectiveness, and welfare aspects. The process involved the ranking of the weighted output of the application of cost-effectiveness analysis (CEA) and the assessment of co-benefits for each measure within a given strategy.

First, the CEA served as comparative assessment of different options that aim to achieve a given objective not measurable in monetary terms [20]. It did so by assessing alternatives in terms of the cost per unit of benefit delivered. In the RESCCUE context, the objective was to increase a city's resilience through the reduction of the floods and CSO spills impacts. The effectiveness of the consecution of this objective was measured through the variation of the recovery time (VRT) from a modeled climate-related event. The recovery time was based on a 1D/2D hydrodynamic model developed to simulate floods in the assessed cities related to a range of return periods. For both case studies, the 1D/2D model was carried out to obtain the time to recover from a flood episode under different measures. An additional 1D drainage model was developed and applied to simulate CSO spills into water bodies and to estimate the average duration of insufficient water quality for the different scenarios modeled. The detailed methodology of both models can be found in [21,22]. The variation of the recovery time for a measure i and event e ($VRT_{i,e}$) was calculated by subtracting the time obtained in the business as usual (BAU) scenario for the same event ($RT_{BAU,e}$) with the one obtained with the measure modeled ($RT_{i,e}$) (Equation (1)):

$$VRT_{i,e} = RT_{BAU,e} - RT_{i,e}. \quad (1)$$

Hydrodynamic modeling is the preferred option to assess the effectiveness of adaptation actions in urban services. However, if a 1D/2D modeling software is not available, a 1D model would also offer an alternative, as it provides the time during which the drainage network is working under surcharged conditions. This surcharged time could be used alternatively as an effectiveness indicator.

The cost was included as the equivalent annual cost (EAC) (Equation (2)), which is the annual estimated cash flow over the lifespan of the project, considering discounting [23]. This allows harmonization of all costs for comparison of measures through the time horizon of the study, set at 2100. They consider initial investment, annual costs, reinvestment (if necessary), and residual value at the end of the assessment time period:

$$EAC_j = \frac{NPV_j}{A_{(t,i)}},\ A_{(t,i)} = \sum\nolimits_{t=1}^{T} \frac{1 - \frac{1}{(1+i)^T}}{i} = \frac{1-(1+i)^{-T}}{i}, \quad (2)$$

where $A_{(t,i)}$ is the annuity factor which is the sum of all discount factors for the duration of the project; T is the time horizon, and i is the discount rate. The discount rate selected for Barcelona and Bristol case studies was 1.23%. It was based on research on the most suitable long-term rate for both regions (Catalonia, Spain and West Country, England) carried out within the European project EconAdapt [24]. This is aligned with the Stern economic school of thought that considers that climate change impact's increases in the long-term future should be accounted for through low or decreasing discount rates [25,26]. Both sites considered the lower range of the discount rate in the scenario modeled with economic growth.

In the case that costs of measures were not available or not accurate enough, a literature review could be carried out in order to develop a scoring system for expected costs of implementation and maintenance of the measures proposed. In the preliminary assessment, costs accuracy of measures is not essential, but actual relative differences between measures is required in order to obtain a realistic preliminary ranking. However, the measures selected to undergo the detailed assessment (next stage) required more accurate results, as their outputs were expected to be more precise.

The equivalent annual costs (EAC) of each measure i divided by its VRT, resulted in the cost-effectiveness assessment (CEA) ratio indicator (Equation (3)). In the framework of increasing urban resilience, the reduction of the city recovery time is an important indicator. Therefore, in the CEA indicator, a "penalty" is levied to those measures that do not reduce it at all. Results were ranked from the most (smaller result) to the least (larger result) preferred option:

$$CEA_i = \left\{ \begin{array}{c|c} \frac{EAC_i}{VRT_i} & if\ VRT_i > 0 \\ EAC_i \times 2 & if\ VRT_i \leq 0 \end{array} \right\}. \quad (3)$$

In parallel, co-benefits were included in order to assess the indirect effects of measures. In both case studies, there was a lack of accessible quantitative information to assess the co-benefits. Although, there was also a strong interest in including them in the prioritization exercise. The solution was found in assessing co-benefits through a site-specific semi-qualitative scoring system, using local and technical experts from each site. Based on the MCA method, stakeholders from both city councils and utilities and technical experts (engineers, economists, and natural scientists) contributed in participatory processes in order to assess the co-benefits [13,27].

In a first round of workshops, there was a selection of indicators from the co-benefits standardization framework in the C40 context by the London School of Economics [13]. From their extensive framework, a multidisciplinary group of experts selected indicators relevant to resilience and urban services. They were classified by economic, social, and environmental co-benefits (Table 1). In a second workshop, the experts working group were asked to score every measure under the selected indicators using a 0 to 10 scoring system. There was a discussion and voting exercise for each indicator and measure, and consensus was found through a session facilitator. Average values were estimated for each category of co-benefit, in order to include average values per category for each measure in the ranking exercise. One should note the caveat related to the quantification of co-benefits related to their extremely context-driven nature [7]. The sign and size of their impact on welfare depend heavily on local circumstances. Therefore, the co-benefits scores assessed for Barcelona and Bristol are unique for those case studies and measures, and new studies should internally assess their own potential co-benefits impacts.

At the end of the second workshop, the working group agreed to assign a weighted percentage to each variable (i.e., CEA (25%) and economic (25%), social (25%), and environmental (25%) co-benefits) in order to align the importance given to the variables with the overall aim of the decision-makers. To calculate the overall ranking, the results of each variable were normalized in order to use a common scale for the different data types on a common scale. Each data point was given a score between 0 and 1, based on its relative position within all values of the variable. This allowed to calculate the weighted scores of each measure per strategy and produce the rankings.

The aim of this phase was to offer coarse results that facilitate decision-makers to shortlist the measures that deserve further analysis. Thus, this stage is only relevant if there is a large number of measures (e.g., more than ten) to be screened. A low number of measures to assess can be considered affordable in terms of finding the resources to carry out a detailed damage assessment for all measures.

3.4. Stage 3: Detailed Assessment of Adaptation Scenarios

3.4.1. Stakeholders' Selection of Sets of Measures for Detailed Assessment

The two groups of stakeholders—city councils and utilities representatives and researchers from the RESCCUE project—held a third workshop with the aim of deciding which measures were worth an in-depth assessment. Using the preliminary ranking results, all members reached a consensus to select the measures, following the MCA method that relies on subjective expert judgement or stakeholder opinion [3]. In these workshops, it was decided that, in the detailed assessment measures, would be grouped by adaptation scenarios, as decision makers sought to understand the impact of implementing combination of measures, rather than individual measures results.

3.4.2. Technical Detailed Assessment: Risks Modeling

Different climate impacts have been assessed for the two case studies of the project RESCCUE. Although other hazards have been addressed, only floods, both pluvial and fluvial, and CSO spills are considered here for comparative purposes of the two cities. Damages due to floods and CSO spills can be many, and these can be classified as direct or indirect, and in turn tangible or intangible [28]. A variety of damages caused by these hazards have been assessed in these two cities, such as flood damages to properties and vehicles, traffic disruption or damages to the electrical grid. Table 2 summarizes the different hazards and risks assessed for each city.

Table 2. Summary of detailed assessments conducted in Barcelona and Bristol.

Case Study	Hazard	Risk Assessment
Barcelona	Pluvial floods	Damage impact to properties and vehicles Intangible damages to pedestrians and vehicles Street waste containers instabilities
	Water quality	CSO spills in bathing areas
Bristol	Pluvial and fluvial floods	Damage impacts to general infrastructures Traffic disruption Energy sector damage
	Water quality	CSO spills

Various methodologies to assess these risks have been employed in the two case studies. In the Barcelona case study, the following detailed assessments were carried out to evaluate the efficiency of the proposed adaptation scenarios within the pluvial flooding strategy:

- Economic damage assessment: a detailed estimation of pluvial flood damages to properties and vehicles was conducted. A 1D/2D hydrodynamic model of the entire city permitted estimation of the flow parameters (i.e., water depth and velocity) on the surface (i.e., city streets) for different return periods of rainfall (i.e., 1, 10, 50, 100, and 100) [29]. Therefore, this urban drainage model output has been used as an input for the flood damage models. The model proposed by Martínez-Gomariz et al. [30] was applied to estimate damages to vehicles, based on the depth-damage curves developed by the US Army Corps of Engineers [31]. A new model to estimate damage to properties in dense urban environments has been developed within the framework of the RESCCUE project. The model was constructed according to the suggestions of an insurance surveyor expert in flood damage appraisals [32]. This model relies on the accuracy of depth-damage curves that were constructed specifically for the city of Barcelona. These curves were developed based on damage claims of previous flood events together with the expert opinion when there was a lack of data [33]. Both models provided a total amount of direct economic damage for properties and vehicles that were aggregated per each return period. With this aggregation, the expected annual damage (EAD) [34] could be determined and used as a risk indicator. Therefore, the difference between the EAD before and after measures implementation provides an indicator of effectiveness of adaptation measures in terms of economic damages reduction.
- Intangible damage assessment: social impacts focused on safety of pedestrians and vehicles exposed to extreme pluvial flood events. Risk was defined as the combination of hazard and vulnerability by Turner et al. [35]. According to this approach, implemented in other previous studies [36,37], hazard assessment is based on the severity and frequency of the surface hydrodynamic variables and is classified based on specific flood hazard experimental criteria regarding pedestrian and vehicular stability in urban flooded areas [38–40]. On the other hand, flood vulnerability for pedestrian was assessed through several indicators like demographic density, percentage of people with critical age, and foreign inhabitants, and the number of critical infrastructures [36,37]. Vulnerability for vehicular circulation was assessed based on the vehicular daily intensity. Finally, a risk matrix combined hazard and vulnerability indexes to express flood risk.
- Stability of street waste containers: flood impacts over the waste collection system were assessed. A specific measure about fixation of waste containers was included in 2 scenarios [29]. The indicator displays results in terms of percentage of reduction of unstable containers.

For the CSO spills reduction strategy, two detailed assessments were carried out to understand the impacts of the adaptation scenarios:

- Direct impacts on human health: insufficient bathing quality time (in hours) during the bathing season was carried, modeled for the coastal areas of Barcelona where CSO events occur [22]. Specifically, pollutant hazard was assessed through a coupled urban drainage and seawater quality model that was developed, calibrated, and validated based on local observations. The study quantified the health hazard of bathing waters affected by CSOs based on two novel indicators: the mean duration of insufficient bathing water quality (1) per bathing season and (2) after single CSO/rain events. More information about the proposed technique to assess human health hazard produced by CSO could be found in [41].
- Indirect impacts on business: potential economic losses as a consequence of closing related businesses (water sports, restaurants by the seaside, and fishing activities) due to bathing waters contamination [42]. Estimations were obtained using revenues of the affected sectors and neighborhoods where CSO spills occur. The relative damage proportion to the total revenue was assigned using the results of a survey and questionnaire carried out to citizens and business owners of the area. Results were expressed in monetary terms.

In the Bristol case study, the evaluation of adaptation measures for pluvial and fluvial flooding was carried out under the following methodology:

- Damage assessment: flood models were developed evaluating property damage through application of the damage assessment tool developed in EU project CORFU (Collaborative Research on Flood Resilience in Urban Areas) [43] and designing intervention scenarios representing property level protection. Flood models included fluvial and pluvial events at a range of return periods (T20 to T1000 and T10 to T100, respectively). Analysis of peak flood depth mapping for a baseline representing current day conditions and a climate change scenario derived from UKCP09 [19], assuming BAU emissions up to the year 2115 was carried out.

A damage cost assessment per scenario was generated by combining flood depths with building classifications [44] and depth-damage curves [45]. Intervention scenarios designed to protect properties within the 20-year flood outlines, either for all residential buildings in the three worst affected areas (zonal target) or for the same number of worst-impacted properties distributed across the study area (individual target), were compared. Interventions were represented by adapting the damage curve to prevent damages below a 600 mm water-depth threshold, reflective of a likely effective level of protection [46].

- Traffic impact assessment: The flood maps that were used for the damage assessment were loosely coupled with micro-simulation traffic model SUMO (Simulation of urban Mobility) [47]. A modified approach outlined by [48] was applied to simulate the effects of flooding on traffic, whereby the speed limits on specific sections of roads were reduced or road sections were close temporarily during a thirty-minute flood event depending on the maximum-recorded flood-depths. For the adaptation scenario, the bridges that cross the central river sections within the city were assumed to be locally protected from flooding in order to observe how—by keeping these specific roads open and unflooded—the flows of traffic within the network could be greatly improved. The impact costs values were derived via the use of speed versus cost table from the multicolored manual (MCM) [45].
- Electricity system: within the Bristol case study, the effect of localized improvements to infrastructure protection were analyzed [49]. Detailed assessment results were achieved by carrying out a sensitivity analysis that altered the fragility (depth vs. infrastructure failure) curves of the electrical substations.

These methodologies have been applied for the BAU scenario, in which no adaptation is considered and for a scenario in which measures are implemented. For instance, once a certain flood is modeled (i.e., 10-year return period design storm), the risk for pedestrians, based on a person's stability threshold, is assessed first without measures (BAU). Afterwards, a measure is implemented in the flood model, which yields a lower flood, and thus the risk is re-assessed. The comparison of both model results yields the variation in the high-risk area for pedestrians, considered an effectiveness indicator of risk reduction measures. Similar procedures have been conducted for the hazards and risks assessments listed in Table 2 for the two cities.

3.4.3. Economic Assessment: Environmental Cost-Benefit Analysis

Cost-benefit analysis (CBA) was the method selected for the final comparison of the potential adaptation scenarios. This method allowed to integrate all previous assessment results involving direct or indirect changes in environmental, economic, and societal variables, translated into monetary terms [6]. It provided a comparative overview of the potential effects of the different scenarios in terms understood by all stakeholders.

The net sum of all relevant positive and negative outcomes of a scenario is known as the total economic value (TEV) [6] and is typically divided between use and non-use (passive) value [6]. In this study, the focus was set on use values, which relate to the actual use of the good in question, as for example, the use of green areas in cities for recreation [6]. Whereas, non-use values are those related to their existence, altruistic or bequest value [6]. When possible, market prices were used to value the changes provided by the measures' implementation (or related goods or services), while benefit transfer was used when direct values were not available. Benefit transfer relies on unit values obtained in previous studies to estimate the value in the study site, adapting them to the characteristics of the new site [50]. Ecosystem services are understood as the direct and indirect contributions of ecosystems to humans [51]. They play an important role, since their principles have been accounted for in the sustainable urban drainage (SUDS) measures [52], in an attempt to demonstrate the benefits of "greening" urban areas. This followed the trend in the urban planning sector of putting emphasis on accounting for the co-benefits provided by nature-based solutions [52–56].

The time horizon selected for the analysis was 2020–2100, aligned with the timespan of the general assessment for the project RESCCUE. Costs included all required investment efforts of each city council, as well as the operating costs for the lifespan of the analysis. Benefits came from two sources. First, the avoided costs were estimated through the difference between the estimated economic damage assessment in the BAU scenario and in each of the alternative scenarios [11]. In addition, monetary values were included to account for the benefits of the improvement in the provision of ecosystem services of SUDS measures. They were adapted using the benefit transfer method [57]. These benefits include the reduction of the heat island effect, which implies reductions on electricity consumption [58,59]; air quality improvements [58]; habitat creation and aesthetic value, related to the increase in willingness to pay for properties with surrounding green areas [59]. Net benefits (Equation (4)) aggregate benefits and costs to determine the TEV or complete impact of the scenarios (j) proposed:

$$\text{Net benefit}_{\text{j}} = \text{Benefits}_{\text{j}} - \text{Costs}_{\text{j}}. \tag{4}$$

The net benefits expected through the lifetime of the project (years from t = 1 to T = 80) were discounted to reflect future values in present terms, obtaining the net present value (NPV) (Equation (5)), using the same discount factor as the CEA. Similarly, the results were annualized for comparative reasons, thus presented using the annual equivalent present value (AEPV) (Equations (6) and (7)), for each scenario j:

$$NPV_j = \sum_{t=1}^{T} \frac{Benefits_{j,t} - Costs_{j,t}}{(1+i)^t}, \tag{5}$$

$$AEPV_j = \frac{NPV_j}{A_{(t,i)}}, \tag{6}$$

$$A_{(t,i)} = \frac{1-(1+i)^{-T}}{i}, \tag{7}$$

where $A_{(t,i)}$ is the annuity factor of the present value.

3.5. Stage 4: Final Ranking

The multiple results obtained through the detailed assessment allowed to rank adaptation scenarios under various criteria. In the Barcelona case study, scenarios were prioritized by: (1) area of risk reduction, (2) by avoided damage, (3) by costs, and (4) by net benefit criteria. In the Bristol case study, scenarios were ranked based on total damage.

4. Results: Application in Two European Cities

The application of the methodology is presented in stages, comparing the two case studies in order to display the different approaches taken.

4.1. Problem Characterization in Practice

The outcome of the first round of workshops held in each city was the definition of the problem characterization (Table 3). The second workshop identified an extensive list of measures and the adaptation strategies to be assessed (Table 4).

Table 3. Description of hazards selected as outcome of the problem characterization.

Case Study	Extreme Event under Assessment	Relevance
Barcelona	Pluvial flooding CSO spills	Climate forecasts predict increases in the frequency of extreme weather events: Increase of 20% for 100 years return period rain (T100) is expected for the period 2041–2070, + 40% expected by the end of the century [18].
Bristol	Fluvial flooding Pluvial flooding CSO spills	Climate forecasts indicate that fluvial and pluvial flood events are likely to worsen in response to an increasing likelihood of extreme rainfall. For example, between 2041 and 2070, the 1 year extreme daily rainfall is predicted to increase from 33 to 58 mm (UKCP09 median value) [19]. The fluvial system is also particularly vulnerable to tidal interference increasing river levels in the city, with UKCP18 projections indicating a 10 cm sea level rise across the 2041 to 2070 horizon, leading to significant areas of the city facing a future threat [60].

Table 4. Description of selected strategies and their measures to be prioritized in the two case studies.

Case Study	Selected Strategies and Their Measures
Barcelona	Pluvial flooding 1. Improvements of surface drainage system 2. Increase of sewer system capacity—New pipes (I) 3. Increase of sewer system capacity—New detention tanks (II) 4. SUDS scheme (increased area of green roofs, infiltration trenches, and detention basins) 5. Early Warning System 6. Self-healing algorithm implemented in the electrical distribution grid 7. Ensure the stability of waste containers Combined sewer overflows (CSO) spills 1. SUDS scheme 2. Early Warning System (EWS) 3. Detention tanks for CSO prevention 4. Improvements of the capacity of sewer interceptor and WWTP 5. End of pipe CSO treatment

Table 4. *Cont.*

Case Study	Selected Strategies and Their Measures
Bristol	Pluvial flooding 1. Property level protection of crucial infrastructure 2. Demountable flood protection barriers 3. Identify high risk areas by carrying out studies of flood modeling analysis Fluvial flooding 1. Flood proof crucial infrastructures 2. Build riverside flood defense walls 3. Demountable flood protection barriers 4. Identify high risk areas by conducting studies involving flood modeling analysis CSO events (in the Ashton Vale area) [1] 1. Inlet diameters increase 2. Disconnecting paved surfaces from the combined system 3. Full surface water separation 4. SUDS scheme (swales, filter trenches, permeable paving, detention basins, mixed schemes) 5. Raising curb heights 6. Increasing surface water sewer system capacity 7. Tide isolation of drainage systems 8. Improvements to watercourse capacities

[1] CSO events strategy is presented in Appendix A, because it was assessed in only one area of the city and thus not comparable with the other two strategies embracing the entire city.

The longlist of adaptation actions related to urban services of Barcelona contained 4 strategies and 27 measures, collected from the local climate action plan and workshops. Stakeholders of the Barcelona case study agreed to focus the efforts on improving the resilience of the city against pluvial flooding and CSO spills events. Therefore, the 2 strategies under assessment are related to those hazards and contained structural, nature-based solutions and technological measures aimed to reduce damages related to those hazards.

In the Bristol case study, 3 strategies and 14 measures related to urban-services were identified initially during the workshops and from local action plans. Stakeholders decided to focus on the improvement of Bristol's resilience against pluvial and fluvial flooding events and CSO spills.

4.2. Preliminary Assessment of Adaptation Measures in Practice

After defining the strategies and their respective measures, CEA and co-benefits were estimated, following the methodology described above. The variables used as an input in the CEA were the results of the hydrodynamic models and annualized costs estimations, whereas the co-benefits scores were obtained by participatory processes of multidisciplinary experts in Barcelona and Bristol. The ranking results of the preliminary assessment in Barcelona and Bristol are presented in Tables 5 and 6 respectively. Weights given to each indicator were determined under consensus during the second workshop, following stakeholders' judgement.

Table 5. Preliminary ranking results for the adaptation measures included in the flood and CSO strategies assessed for the Barcelona case study.

	Weights Given	**25%**	**25%**	**25%**	**25%**
Rank	**Pluvial Flooding Strategy Measures**	**CEA (€/h)**	**Economic**	**Social**	**Environmental**
1	SUDS (green roofs, infiltration trenches, detention basins for rural catchments)	16,466,678	56%	69%	85%
2	Ensure the stability of waste containers	24,010	13%	13%	5%
3	Early Warning System	29,478	13%	13%	5%
4	Increase of sewer system capacity—new pipes (I)	5,597,181	13%	60%	35%
5	Increase of sewer system capacity—new detention tanks (II)	18,687,976	1%	71%	34%
6	Improvements of surface drainage system	4,072,897	11%	41%	9%
7	Self-healing algorithm in the electrical distribution grid	127,304	10%	0%	0%
Rank	**CSO Strategy Measures**	**CEA (€/h)**	**Economic**	**Social**	**Environmental**
1	SUDS	584,465	56%	69%	85%
2	Early Warning System	1528	13%	13%	5%
3	Detention tanks	452,461	1%	71%	34%
4	End of pipe CSO treatment	4,687,158	9%	29%	8%
5	Improvements of the capacity of sewer interceptor	59,500	1%	17%	8%

Table 6. Preliminary ranking results for the adaptation measures included in the pluvial and fluvial strategies within the central area of Bristol.

	Weights Given	**25%**	**25%**	**25%**	**25%**
Rank	**Pluvial Flood Strategy Measures**	**CEA (€/h)**	**Economic**	**Social**	**Environmental**
1	Demountable flood protection barriers	7243	39%	81%	39%
2	Identify high risk areas (flood modeling analysis studies)	60,790	23%	57%	14%
3	Flood proof crucial infrastructures	134,608	7%	3%	14%
Rank	**Fluvial/tidal Flood Strategy Measures**	**CEA (€/h)**	**Economic**	**Social**	**Environmental**
1	Demountable flood protection barriers	8450	39%	81%	39%
2	Build riverside flood defense walls	3,749,280	64%	87%	41%
3	Identify high risk areas by conducting studies involving flood modeling analysis	56,509	23%	57%	14%
4	Flood proof crucial infrastructure	177,683	7%	3%	14%

Table 5 presents SUDS measures as the preferred option, followed by structural measures for both strategies. The equal distribution of weights between indicators implies that those with larger indirect benefits are prioritized over the ones that are just more cost-effective. The reinforcement of the stability of waste containers is the second option for the floods strategy, and the early warning system for the CSO strategy.

Table 6 shows that demountable flood protection barriers are the most preferred measure for protection against pluvial flooding and for fluvial and tidal flooding, combined in this instance with riverside defense walls that offer protection up to a 1 in 200-year event (ranked second). For the Ashton Vale region (Appendix A), a wider range of measures were selected to offer improved protection against pluvial flooding and reduce CSO spills events.

4.3. Detailed Assessment in Practice

4.3.1. Selection of Adaptation Scenarios

Results from the first ranking exercise gave stakeholders insights on the advantages and disadvantages of the measures proposed. This facilitated the discussion regarding the selection of the most relevant measures to include in the adaptation scenarios, aimed to answer different policy questions. For example, in the case of Barcelona's strategy for pluvial flood impacts reduction, there was a clear interest from policy-makers in the co-benefits provided the SUDS measures, while technical experts highlighted the potential reduction of risks and recovery time offered by the structural measures, although the costs of the latter were high and therefore difficult to meet. Therefore, they decided to assess the potential impact of implementation of SUDS across the entire city, while the structural measures were divided by zones. Adaptation scenarios were created to obtain results for those requests (Table 7). Regarding the stability of waste containers, detailed assessment was not found relevant, as the preliminary assessment already displayed a low CEA result, which was enough to be included in the new Climate Action Plan for Barcelona.

Table 7. Description of adaptation scenarios selected for Barcelona for the two strategies assessed.

Strategy Name	Adaptation Scenarios (AS)
Pluvial flooding impacts reduction	1. Flood_AS1. SUDS emplaced through the entire city 2. Flood_AS2. SUDS and structural measures (SM) through the entire city 3. Flood_AS3. SUDS (entire city) and SM within Zone 1 (Z1) 4. Flood_AS4. SUDS (entire city) and SM within Zone 2 (Z2) 5. Flood_AS5. SUDS (entire city) and SM within Zone 3 (Z3) 6. Flood_AS6. SUDS (entire city) and SM within Zone 4 (Z4) 7. Flood_AS7. SUDS (entire city) and SM within Zone 5 (Z5) 8. Flood_AS8. SUDS (entire city) and SM within Zone 6 (Z6)
CSO spills reduction	1. CSO_AS1. SUDS emplaced through the entire city 2. CSO_AS2. SUDS (entire city) and detention tanks

In the Bristol case study, the needs of stakeholders guided the way adaptation strategies were categorized (Table 8). City council representatives were most concerned with fluvial flooding linked to the River Avon, its associated watercourses and tidal interactions of the Severn Estuary, alongside pluvial flooding originating from extreme rainfall across the urban area. The interest was again on gaining knowledge on the zonal assessment of the city, although structural measures were identified as the most promising interventions. Due to restrictions in budgets, the Bristol case study chose to investigate only the use of property level protection, since it allowed adaptation measure assessment using previous flood modeling.

4.3.2. Detailed Assessment Results

In the Barcelona case study, the technical and economic assessments were carried out for the proposed adaptation scenarios related to flooding and CSO reduction strategies. The economic damage assessment provided the expected annual damages (EAD) for each scenario. Comparing the scenarios against the BAU, the avoided damage was estimated for each adaptation scenario. These were accounted as benefits in the CBA. Ecosystem services were included as benefits provided by the SUDS measures thus present in all adaptation scenarios. Costs were estimated for the adaptation scenarios, adjusting the previous estimates for individual measures of the CEA to the new adaptation scenarios. Net benefits were obtained in the CBA for each scenario.

Furthermore, for the flooding reduction strategy, estimates from the intangible damage assessment gave the percentage of high-risk area reduction for pedestrians and vehicles for each scenario.

In the Bristol case study, a detailed analysis of the proposed adaptation scenarios was undertaken using a different approach. Stakeholders were more interested in the potential impacts of different intensities events for two scenarios and compare them to the BAU. Measures were ranked based on the total damage costs expected during a range of extreme flood events in the city. The assessment was calculated by developing a baseline of expected flood damages during a flood event in the future, and comparing them to the expected flood damages with property level protection applied to targeting buildings or strategic zones.

Table 8. Adaptation scenarios for each strategy in Bristol case study.

Strategy Name	Adaptation Scenarios (AS)
Pluvial flooding impacts reduction	1. Pluvial_AS1. BAU with climate change 2. Pluvial_AS2. BAU CC with zonally targeted interventions 3. Pluvial_AS3. BAU CC with individually targeted interventions
Fluvial flooding impacts reduction	1. Fluvial_AS1. BAU with climate change 2. Fluvial_AS2. BAU CC with zonally targeted interventions 3. Fluvial_AS3. BAU CC with individually targeted interventions

4.4. Final Ranking: Results of the Detailed Assessment

The results from the detailed assessment provided information to generate four prioritization rankings relevant for stakeholders (Tables 9 and 10), three of them contained monetary criteria—avoided damage, net benefits and costs, and one was in percentage terms, representing the high-risk area reduction.

Table 9. Prioritization results under the 3 monetary criteria for pluvial flooding in Barcelona.

Rank	Avoided Damage		
	ID	**Scenario**	**AEPV (Million €/Year)**
1	Flood_AS2	SUDS + Structural measures entire city (SM)	49.0
2	Flood_AS7	SUDS + SM in Z5	43.1
3	Flood_AS4	SUDS + SM in Z2	41.9
4	Flood_AS5	SUDS + SM in Z3	41.7
5	Flood_AS8	SUDS + SM in Z6	41.2
6	Flood_AS6	SUDS + SM in Z4	40.2
7	Flood_AS3	SUDS + SM in Z1	40.0
8	Flood_AS1	SUDS entire city	23.7
Rank	**Costs**		
	ID	**Scenario**	**AEPV (Million €/Year)**
1	Flood_AS1	SUDS entire city	9.9
2	Flood_AS6	SUDS + SM in Z4	10.9
3	Flood_AS8	SUDS + SM in Z6	11.0
4	Flood_AS5	SUDS + SM in Z3	11.6
5	Flood_AS7	SUDS + SM in Z5	12.2
6	Flood_AS4	SUDS + SM in Z2	12.3
7	Flood_AS3	SUDS + SM in Z1	15.1
8	Flood_AS2	SUDS + SM entire city	22.4

Table 9. *Cont.*

Rank	Net Benefits		
	ID	Scenario	AEPV (Million €/Year)
1	Flood_AS7	SUDS + SM in Z5	39.6
2	Flood_AS8	SUDS + SM in Z6	38.9
3	Flood_AS5	SUDS + SM in Z3	38.7
4	Flood_AS4	SUDS + SM in Z2	38.3
5	Flood_AS6	SUDS + SM in Z4	38.1
6	Flood_AS2	SUDS + SM entire city	35.3
7	Flood_AS3	SUDS + SM in Z1	33.6
8	Flood_AS1	SUDS entire city	22.5

Table 10. Prioritization results under high-risk area reduction criterion for pluvial flooding in Barcelona.

Rank	Risk Reduction (T10)					
	ID	Scenario	Risk for Pedestrians	ID	Scenario	Risk for Vehicles
1	Flood_AS2	SUDS + SM entire city	99%	AS2	Str. BCN + SUDS	99%
2	Flood_AS3	SUDS + SM in Z1	79%	AS7	Z5 + SUDS	90.4%
3	Flood_AS4	SUDS + SM in Z2	79%	AS4	Z2 + SUDS	90.2%
4	Flood_AS7	SUDS + SM in Z5	77%	AS3	Z1 + SUDS	87.2%
5	Flood_AS5	SUDS + SM in Z3	76%	AS5	Z3 + SUDS	86.6%
6	Flood_AS6	SUDS + SM in Z4	74%	AS8	Z6 + SUDS	85.4%
7	Flood_AS8	SUDS + SM in Z6	65%	AS6	Z4 + SUDS	84.1%
8	Flood_AS1	SUDS entire city	34%	AS1	SUDS	45%

The aim was to provide as much information as possible to solve the concerns of decision makers regarding the different aspects of the policy making process, i.e., budgetary, welfare, and risks. The BAU scenario is omitted from the ranking as the objective of the city council is to act against floods. For the avoided damage and risk reduction criteria, the preferred scenario is to implement SUDS and structural measures in the entire city of Barcelona; whereas for the net benefit criteria, the scenario with SUDS and structural measures in zone 5 ranks first. In the case of cost criteria, the SUDS measures are the preferred option. The zone 5 scenario also ranks high for the rest of the criteria. This is expected to support stakeholders by facilitating the decision-making process of implementing adaptation measures. More detailed results of the risk assessment can be found in Appendix B.

The prioritization exercise for the CSO strategy (Table 11) was carried out using 3 monetary criteria (i.e., avoided damage, costs, and net benefits), using the outputs from the CBA that used the damages analysis results.

Table 11. Results of ranking of adaptation scenarios selected for CSO under the three selected criteria in Barcelona.

Rank	**Avoided Damage**	
	Scenario	AEPV (€/year)
1	CSO_AS2. SUDS and detention tanks	18,352,567
2	CSO_AS1. SUDS (entire city)	10,041,691
Rank	**Costs**	
	Scenario	AEPV (€/year)
1	CSO_AS1. SUDS (entire city)	9,918,794
2	CSO_AS2. SUDS and detention tanks	16,145,628
Rank	**Net Benefits**	
	Scenario	AEPV (€/year)
1	CSO_AS2. SUDS and detention tanks	10,850,498
2	CSO_AS1. SUDS (entire city)	9,078,777

These results helped decision-makers to understand the most advantageous adaptation measures given their selected criteria, which might be subject to maximizing net welfare gains, or minimize costs or damages. If the avoided damage and net benefits criteria are considered, the scenario of combined SUDS and tanks was preferred, whereas if the criterion follows cost-efficiency, the SUDS scenario ranked first.

The results of the detailed assessment carried out in the Bristol case study provided a rank based on the total damage costs expected during a range of extreme flood events in the city for pluvial and tidal/fluvial flood scenarios (Tables 12 and 13).

Table 12. Estimated total flood damages resulting from extreme pluvial flood events to all building classes for different return periods (T*year*s) (£) in Bristol.

Rank	Scenarios	T10	T20	T30	T100
1	BAU CC with individually targeted interventions	31,880,000	45,322,000	-	96,796,000
2	BAU CC with zonally targeted interventions	35,218,000	48,312,000	-	98,804,000
3	Business as usual, considering climate change impact (BAU-CC)	36,692,000	50,088,000	-	100,757,000

Table 13. Estimated total flood damages resulting from extreme tidal/fluvial flood events to all building classes for different return periods (T*year*s) (£) in Bristol.

Rank	Scenarios	T20	T100	T200	T1000
1	BAU CC with individually targeted interventions	-	155,695,000	482,760,000	537,228,000
2	BAU CC with zonally targeted interventions	-	156,622,000	482,738,000	537,258,000
3	BAU-CC	-	160,006,000	483,009,000	537,446,000

The analysis identified that the most effective intervention scenario was individually targeted property level protection to reduce the impact of both pluvial and fluvial flooding hazards. The results of the total damage assessment, of the previous CEA and co-benefits results were detailed enough for stakeholders, and therefore a complete CBA was considered not necessary for Bristol's decision-makers. Instead, stakeholders were more interested in understanding the changes pertaining to the traffic and energy sectors when the selected scenario was applied. Therefore, in the traffic sector, the effectiveness of the adaptation scenario was evaluated by comparing the reduction in recovery time, vehicular cost estimations with respect to their average speed, and PMx emissions, under flooded conditions compared to dry weather conditions [61]. The energy sector's detailed assessment compared the BAU scenario to the selected scenario under different levels of fragility curves of the electrical substations, to provide further information to decision makers on the potential impacts reduction generated by the measures proposed [49].

5. Discussion

The present methodology is built upon existing knowledge of applied quantitative and qualitative methodologies related to urban climate change adaptation and resilience. The flexibility of the methodology was a key feature, and it has been achieved by introducing iterative stakeholder engagement in each stage. The fact that multidisciplinary research groups worked along with city councils and other stakeholders, gave the methodology a practical focus that included tools to face the most common barriers and opportunities met by most climate change adaptation working groups, such as lack of data sources. The methodology offers a modular system that is able to adapt to the realities of the different case studies, allowing to select the required steps for each case. Another advantage is the use of existing and proved methodologies, which are common to stakeholders, with known strengths and weaknesses.

The potential to combine technical, economic, social, and environmental results is a powerful policy instrument, as their decision-making process must consider all those aspects that affect the present and future of their citizens' welfare [2]. It is particularly relevant for those cases where there are many measures that need to be screened and not enough time or capital resources to do so with the necessary detail to support policy decision-making. In that sense, co-benefits assessment in climate adaptation projects can contribute substantially to policy decision-making [62]. First, it is suggested that most co-benefits display positive welfare outcomes in the short term—for example, air pollution improvement, which is the concern of policy makers; whereas direct climate change policy benefits—such as heavy flood damage reduction—may only be perceived in the long term. Second, the co-benefits are usually enjoyed at a local or regional scale and thus are closer to the citizens bearing the costs, they provide incentives for decision makers to act [62].

The methodology enabled the views and expertise of multiple stakeholders to be included through workshops. It has the benefit of fewer requirements from the CEA during the first stage, although the outcomes lack sound conclusions. The uncertainty of results decreases with the participatory process of multidisciplinary experts and further detailed assessment to the selected measures.

The involvement of policy-makers from the beginning of the analysis was regarded as positive, compared to traditional approach of just presenting final results through an assessment report. In addition, such an engagement captured local expertise, enabling intervention development to progress with the understanding of specific high-risk areas and ongoing organizational initiatives. The stakeholder engagement was also able to capture mixed priorities from different groups and integrate this understanding within the context of a wider RESCCUE analysis, drawing together a network of interconnected infrastructure, including the energy, transport, and waste-water sectors. If consultation is transparent and well-structured, it can give valuable insights of local knowledge [27].

Although the focus of the present work is on urban infrastructure and services, it does not neglect social-oriented policies. However, it recognizes that these "soft" policies, such as encouraging residents to change public behaviors [63], belong to a different field of study and policy-making process, out of the scope of this work. However, the final goal of both types of policies is similar: to increase wellbeing, either from a psychosocial perspective or by reducing physical risks and damages.

One of the main barriers for urban adaptation assessment is the general lack of standardized data and/or time resources. Adapting the approach to accommodate varying data availability was an additional challenge. Furthermore, researchers found difficult to align work across stakeholders and case studies, due to existing differences in policy approaches, priorities, and types of stakeholders and their involvement. Another drawback of the methodology is that the co-benefits are city-specific and subject to the expert criteria. Analyses based on experiences, data, and perspectives from stakeholders are based on historical hazard impacts, rather than providing a true representation of future risks. This potential bias can be minimized if robust climate change forecasting and risk and damage modeling is introduced in the assessment. Therefore, although the hydrological model (suggested in the methodology to assess the recovery time) increases the technical expertise demand in the preliminary stage, it is essential to secure informed decision-making throughout the process. In addition, it is an established technique, and the exercise is not as complex as the detailed damage and risk assessment proposed in the third stage, which is highly recommended for final decision-making.

A limitation of an approach grounded in stakeholder engagement is the need to manage conflicting priorities and adjust messages to an audience with varying levels of expertise. This is particularly relevant when managing organizational and community stakeholders, where costs and benefits of intervention actions may not be aligned. Unconscious bias, such as exposure to specific hazards or experience may also influence engagement, leading to a focus on specific issues at the expense of a broader analysis. These issues have been addressed in RESCCUE through engaging a diverse group of technical stakeholders who shared their expertise and results to multidisciplinary audiences.

Similarly, highly spatial hazards such as pluvial flooding can be very dependent on unknown or unpredictable factors which may not have occurred during past events; for example, aging infrastructure may block previously functioning drainage features and significantly alter the response of urban catchments rainfall. These issues cannot be fully mitigated, and for that reason, it was crucial that the methodology recognized those limits by including historic and experiential data. In fact, the consequences of a changing climate and the continuing paving of urban areas (increased permeability) lessen the validity of decision based on historical facts.

Future recommendations to expand the replicability potential is to create a web-based assessment tool to facilitate the implementation in other urban areas.

6. Conclusions

The methodology recognizes that there are several viable strategies with different contributions to society and the aim of researchers is not selecting the best for each case, but to provide results from different perspectives to support city planners to take better-informed decisions.

Combined assessments of technical, socio-economic, and environmental aspects provide added value to policy makers, compared to assessment results addressing only one feature. Their role is to consider multiple aspects that may affect the citizens they represent when selecting a policy or project.

The relevance of scientific research and multidisciplinary technical assessment is only revealed when it is coupled and in harmony with the needs of decision-makers and citizens. Certainly, that was the focus of the present methodology and it was highly valued during its application. Therefore, the results presented here are expected to provide relevant tools for stakeholders to take informed decisions regarding adaptation to climate change in urban areas.

Author Contributions: Conceptualization, M.G.-H. and E.M.-G.; methodology, M.G.-H., E.M.-G. and M.T.-R.; validation, M.T.-R., J.W. and B.E.; formal analysis, M.G.-H., E.M.-G., B.R. and L.L. (Barcelona case study); B.E. and J.W. (Bristol case study); investigation, M.G.-H.; data curation, M.G.H.; Writing—Original draft preparation, M.G.-H.; Writing—Review and editing, M.G.-H., E.M-G. and M.T.-R.; supervision, E.M.-G.; project administration, E.M.-G.; funding acquisition, E.M.-G. and M.G.-H. All authors have read and agreed to the published version of the manuscript.

Funding: This research, under the RESCCUE Project, was funded by the European Commission Horizon2020 funding program. Grant Agreement No. 700174.

Acknowledgments: The authors are grateful to BCASA (from Barcelona City Council) and Bristol City Council for their contributions and insights to implement the methodology and fit it into their new Drainage Master Plans. Thank you also to all partners of the Project RESCCUE for their work during the 4 years of the project, which made this work possible.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Ranking of pluvial flood related measures based on effectiveness and co-benefits within the Ashton Vale area of Bristol with respect to flooding.

	Proposed Weights	**25%**	**25%**	**25%**	**25%**
Rank	**CSO Proposed Measures**	**CEA (€/h)**	**Economic**	**Social**	**Environmental**
1	Inlet increase	8750	36%	60%	35%
2	Disconnecting paved surfaces from (combined) sewer system	6332	33%	10%	36%
3	Swale	9629	26%	40%	55%
4	Surface water separation	4197	6%	13%	23%
5	Filter trenches	9629	26%	40%	41%
6	Permeable paving	9629	23%	43%	40%

Table A1. *Cont.*

	Proposed Weights	25%	25%	25%	25%
Rank	**CSO Proposed Measures**	**CEA (€/h)**	**Economic**	**Social**	**Environmental**
7	Raise curb height	1319	4%	4%	0%
8	Increase of combined sewer system capacity	32,013	1%	71%	34%
9	Sustainable Urban Drainage systems (SUDS)	9629	14%	20%	40%
10	Detention basin	9629	6%	13%	9%
11	Increase surface water sewer system capacity	17,097	6%	0%	0%
12	Improvements to drainage system (watercourse)—isolation from high tide conditions in River Avon	334,056	10%	9%	5%
13	Improvements to drainage system (watercourse)—capacity	158,973	6%	0%	0%

Appendix B

This appendix is aimed to present more detailed results of the assessment carried out for the assessment of pedestrian and vehicles under different return periods in Barcelona. Table A2 displays the risk assessment results for the 5 different return periods assessed for all scenarios in the Barcelona case study. Table A3 displays results of expected annual damage (EAD) in monetary terms for the same cases. Whereas, Figures A1 and A2 represent the assessment of the stability of waste containers carried out.

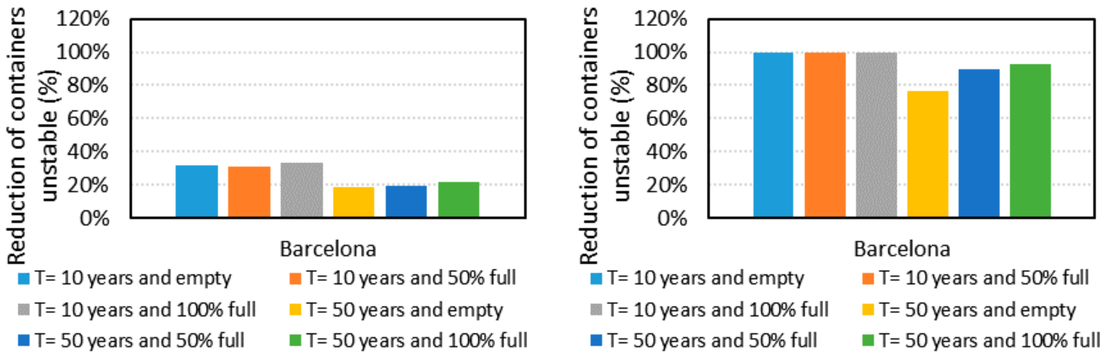
Table A2. Results of pluvial flood risk reduction assessment for pedestrian and vehicles under different return periods in Barcelona.

Adaptation Scenario		Risk Reduction for Pedestrians					Risk Reduction for Vehicles				
		T1	**T10**	**T50**	**T100**	**T500**	**T1**	**T10**	**T50**	**T100**	**T500**
1	SUDS Entire BCN	0%	34%	20%	17%	14%	0%	45%	25%	21%	14%
2	SUDS + Structural Measures Entire BCN	0%	99%	87%	76%	59%	0%	99%	94%	87%	66%
3	SUDS + Structural Measures Zone 1	0%	79%	65%	58%	48%	0%	87%	74%	65%	49%
4	SUDS + Structural Measures Zone 2	0%	79%	63%	56%	47%	0%	90%	76%	67%	51%
5	SUDS + Structural Measures Zone 3	0%	76%	63%	55%	45%	0%	87%	75%	66%	50%
6	SUDS + Structural Measures Zone 4	0%	74%	59%	53%	47%	0%	84%	69%	59%	48%
7	SUDS + Structural Measures Zone 5	0%	77%	62%	55%	48%	0%	90%	71%	61%	48%
8	SUDS + Structural Measures Zone 6	0%	65%	60%	55%	45%	0%	85%	68%	60%	45%

Table A3. Expected annual damage (EAD) from pluvial floods for properties and vehicles for all adaptation scenarios modeled in the Barcelona case study.

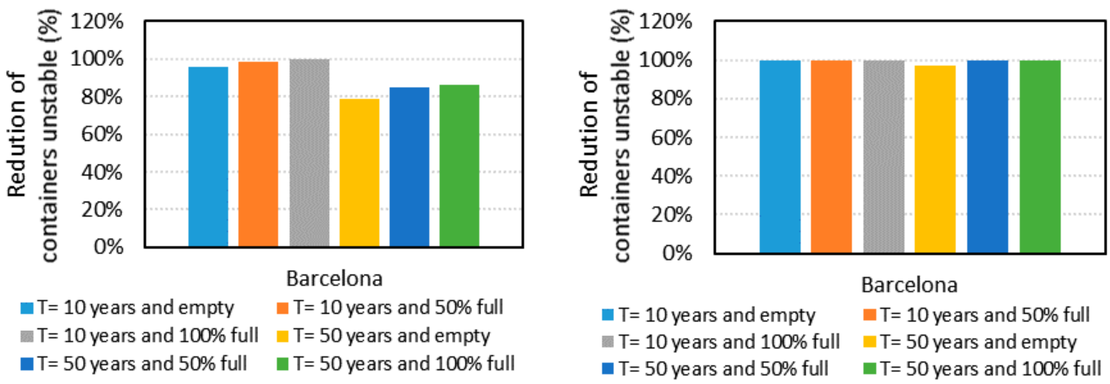
Scenario		EAD to Properties	EAD to Vehicles	EAD Variation
0	Baseline (current rainfall)	31,150,112 €	3,275,292.05 €	-
1	BAU [1] (future rainfall)	44,494,008 €	4,482,544.03 €	+42% (vs. Baseline)
2	SUDS Entire city [2]	23,680,855 €	2,747,960.30 €	−46%
3	SUDS + Structural Measures (SM) Entire city	2,235,685 €	341,720.20 €	−95%
4	SUDS + SM Zone 1	10,270,756 €	825,019.44 €	−77%
5	SUDS + SM Zone 2	8,408,240 €	927,384.48 €	−81%
6	SUDS + SM Zone 3	8,509,119 €	970,750.84 €	−81%
7	SUDS + SM Zone 4	9,821,973 €	999,403.93 €	−78%
8	SUDS + SM Zone 5	7,403,553 €	771,070.23 €	−83%
9	SUDS + SM Zone 6	8,888,035 €	1,008,856.05 €	−80%

[1] BAU is compared to baseline and all adaptation scenarios are compared to BAU; [2] SUDS are assessed for the entire city of Barcelona in all scenarios.



(**a**) Without fixation pieces (Flood_AS1) (**b**) With fixation pieces (Flood_AS10)

Figure A1. Reduction of the number containers potentially unstable at a city scale once applied (**a**) Flood_AS1 and (**b**) Flood_AS10.



(**a**) Without fixation pieces (Flood_AS2) (**b**) With fixation pieces (Flood_AS11)

Figure A2. Reduction of the number containers potentially unstable at a city scale once applied (**a**) Flood_AS2 and (**b**) Flood_AS11.

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